CALIBRATION OF REGIONAL SEISMIC STATIONS IN THE MIDDLE EAST WITH SHOTS IN TURKEY

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ABSTRACT

The objective of this project is to calibrate regional travel-times and propagation characteristics of seismic waves in Turkey and surrounding areas in the Middle East in order to enhance detection and location capabilities in the region. Important data for the project will be obtained by large calibration shots in central and eastern Turkey.

The first, a two-ton shot, was fired in boreholes near Keskin in central Anatolia on 23 November 2002. The explosives were placed in 14 holes, each 80 m deep, arranged in concentric circular arrays. Ninety temporary seismic stations were deployed within a 300 km radius around the shot. The permanent stations of the Turkish National Seismic Network provided a good azimuthal coverage as well as three radial traverses. Most stations within a radius of 200 km recorded the shot. Travel-time data have been analyzed to obtain a detailed crustal model under the shot and along the profiles. The model gives a 35-km thick crust, characterized by two layers with velocities of 5.0 and 6.4 km/s. The P_n velocity was found to be 7.8 km/s. The crustal thickness decreases to the north where the profile crosses the North Anatolian fault. There is a slight increase in crustal velocities, but no change in crustal thickness to the west. Data analysis effort is continuing to refine the regional velocity models and to obtain station corrections.

OBJECTIVES

The Eastern Mediterranean, Caucasus, and many parts of the Middle East are characterized by complex tectonics, and lateral variations of crust/upper mantle structures and seismic velocities. These complexities affect the detection, location, and characterization of seismic events. The primary objective of this project is to improve event location capabilities in the Middle East using calibration shots in Turkey. Specific objectives are: (1) calibrate regional travel-times and propagation characteristics of seismic waves across the Middle East and Eastern Mediterranean; (2) calibrate local and regional models for specific International Monitoring System (IMS) stations in Turkey; (3) conduct reciprocity experiments where feasible; and (4) provide data and models to enhance IMS detection and location capabilities in the region. The calibration data will be generated by two shots in Turkey, one in central Anatolia, and another in eastern Turkey.

RESEARCH ACCOMPLISHED

The first calibration shot was fired in central Turkey near Keskin in November 2002. The explosives (dynamite) were loaded into 14 holes, each drilled to a depth of 80 m, in granite outcrop. Shot holes were located in two concentric circles with radii of 4 m and 9 m, respectively. Two tons of dynamite, about 143 kg per hole, was loaded into the boreholes. Figure 1 shows the location of the shot on a map of Turkey, regional geology, and the geometry of the drill holes. The coordinates of the shot point are: 49°43'29.9"N and 33°38'08.0"E. Elevation is 1425 m. The explosion took place in two steps. First, two holes containing 280 kg of explosives, were detonated on November 23, 2002, at 22:47:33.40 UT. The main shot was fired a day later on November 24, 2002, at 21:10:04.80. It consisted of about 1,720 kg explosives in 12 holes. All holes were detonated at the same time with zero time delay. The shots were fired around midnight local time in order to minimize seismic noise due to cultural activities and atmospheric effects.

Eighty new (temporary) seismic stations were installed to monitor the shot. These complemented about 30 permanent seismic stations, within 500 km of the shot point, operated by the Kandilli Observatory and Earthquake Research Institute (KOERI). Twenty-three of the temporary stations (10 broadband and 13 three-component short period) were shipped from the United States. All others were provided by KOERI and cooperating institutions in Turkey. The distribution of seismic stations is shown in Figure 2. Two linear arrays of short period instruments were deployed to the north and to the southeast of the shot point. A third, less regular profile, was deployed to the southwest. The linear arrays were designed for crustal structure studies and for potential reciprocity experiments. The other stations, especially the broadband instruments, were deployed to provide good azimuthal coverage around the shot.

Unfortunately, there was a strong storm affecting most of Turkey at the time of the experiment. Before the explosion, heavy rains and snow in some areas made the checking and servicing of 80 temporary stations especially difficult. In spite of the weather, all but eight of the stations operated normally and large amounts of good quality seismic data were acquired. Although the retrieval of data from a variety of seismic instruments used in the experiment was a time-consuming task, this task was completed and a database was generated.

The analysis of the shot data is continuing. In this report we describe the initial results concerning crustal structure.

Crustal Structure

The three seismic arrays shown in Figure 2 provide the first opportunity to obtain a well-constrained crustal structure profile in central Turkey. The crustal structure and P_n velocities of the Anatolian plateau have been studied by various methods (Canitez and Toksöz, 1980; Gurbüz and Evans, 1991; Hearn and Ni, 1994; Turkelli et al., 1996; Mangino and Priestly, 1998; Gok et al., 2000; Laske et al., 2001). These studies found crustal thicknesses ranging from about 35–40 km, P_n velocities between 7.6 and 7.9 km/sec, and crustal velocities quite different from each other. None of these studies included long refraction lines.

The travel-time data (three profiles) provide the first opportunity to determine crustal structure and upper mantle velocities for P-waves in the Anatolian plateau. For each profile, velocity models are obtained by fitting the travel-times with a two-dimensional (2-D), laterally varying velocity model. The starting model is generated using a one-dimensional layered model. These models are revised to improve fit to observed travel times. A 2-D ray-tracing

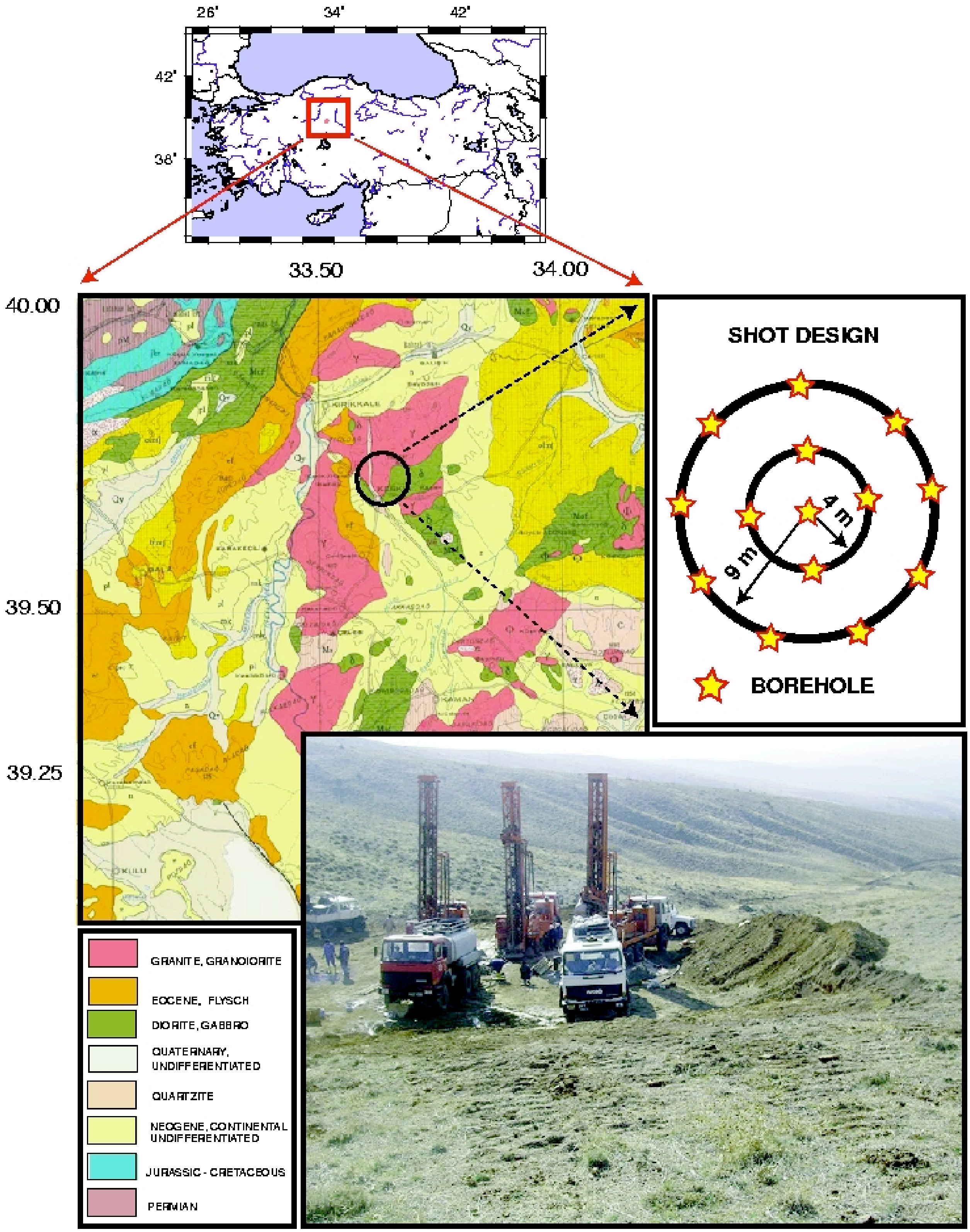

Figure 1: The shot point. Counterclockwise from top: (a) Location of shot point. (b) Geology of shot point vicinity. (c) Drilling of boreholes. (d) Geometry of shot holes.

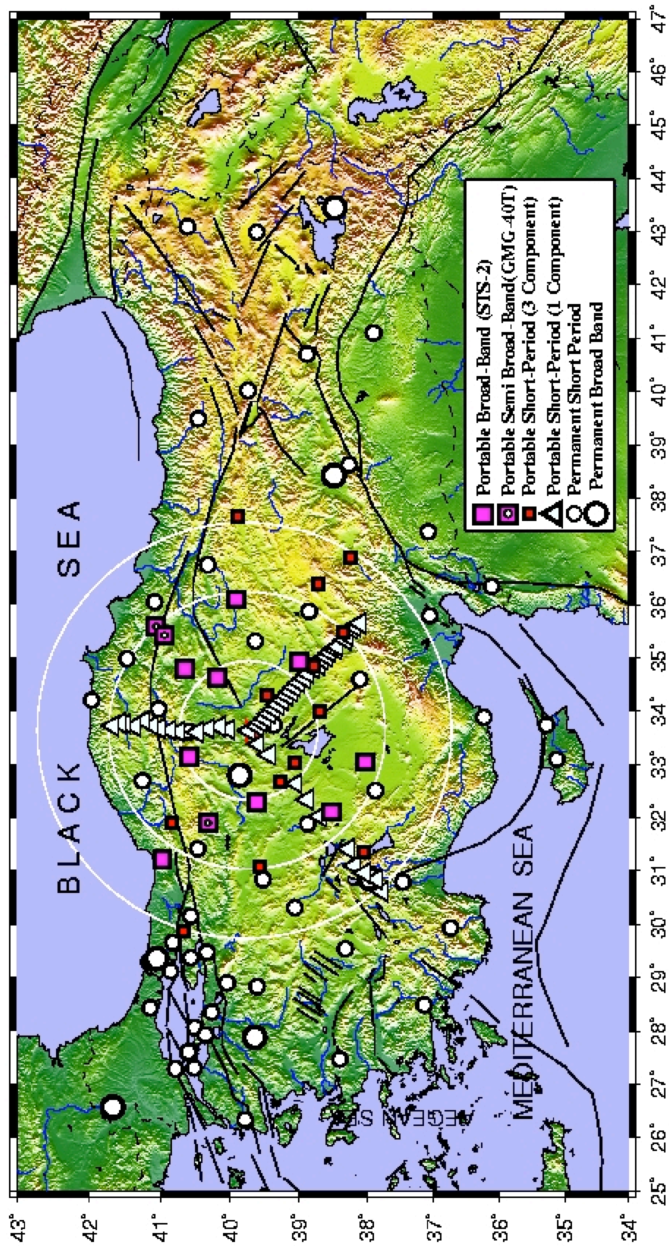

Figure 2: Distribution of seismic stations around the shotpoint. Circles are of 1°, 2°, and 3° radii. Symbols designate station types. Three refraction profiles going north, southeast, and southwest are shown by high density station arrays (triangles). Major faults are also shown.

program is used for calculating travel-times. Velocity gradients, which are included in modeling, are adjusted to improve fit both to travel-times and amplitudes. All structured information obtained is based on forward modeling only.

Figures 3, 4, and 5 display the seismograms (i.e., record section), the travel-times and 2-D velocity models for the north, southeast, and southwest profiles. The seismograms are filtered with a 4–10 Hz bandpass filter to reduce the noise. Signal-to-noise ratio is good up to about 180 km in all profiles with the exception of a few noisy stations. Beyond a distance of 200 km, identifying the first arrivals becomes more challenging. We used different pass-band filters, based on the noise characteristics, at different stations to improve the signal-to-noise ratio. Frequency changes associated with the signals were helpful in identifying the arrivals.

Northern profile. The velocity model for the northern profile (Figure 3) shows a crust with two prominent layers. There is an increase of velocity with depth in the thicker crustal layer, but no evidence of a prominent discontinuity. The average velocity in the top layer is about 5 km/sec and the lower layer about 6.4 km/sec. The uppermost mantle velocity is 7.8 km/sec to 7.9 km/sec. The crustal thickness is 36 km under the shot. There is a prominent change in crustal thickness 120 km north of the shot. There is also an anomaly in the top crustal layer. This anomaly corresponds to the trace North Anatolian fault. The seismic profile crosses the fault 120 km north of the shot point. There is a prominent Bouger gravity anomaly associated with the fault. The 5-km crustal thinning across the fault is consistent with the Bouger anomaly.

Southeastern profile. The record section, travel-times, crustal structure, and velocities are shown in Figure 4. The crustal model shows some prominent features. The thickening of the uppermost layer at 100 km distance is quite well-constrained. It seems to correspond to a little known Gumuskent fault. The noisy station at 100 km may have been situated in the fault zone. The anomaly at about 170 km that affects both the upper layer and the crustal thickness corresponds to the Ecemis fault. This fault is mapped. It has little seismic activity. It is not as prominent as the North Anatolian fault that crosses the northern profile. The crustal thickness along this profile is 36 km, possibly thinning slightly toward the southwest.

Southwestern profile. This profile, shown in Figure 5, has the fewest stations. The quality of the data is excellent. Because of the sparse coverage, the crustal model shown should be considered "tentative." We will try to test this model by calculating fully elastic synthetic seismograms to match the observed records.

Location of the Shot

To locate the shot we used the P-wave arrival times from a well-distributed subset of our seismic stations. The stations used for this study are shown in Figure 6. For the location we used a 1-D velocity model and hypoinverse.

Three velocity models were used for the location. These included AK 135, the model used by KOERI, and a simplified 1-D velocity model derived from the average of three velocity profiles described in the previous section. The velocity models are shown in Figure 6b. The results are summarized in Table 1. All models give good locations, including accurate depths and origin times. The MIT model, based on a new velocity model, does the best.

Table 1: Shot location, and the errors, using P-wave times and three velocity models.

	AK135	KOERI	MIT
Epicenter	39.722N, 33.657E	39.720N, 33.662E	39.724N, 33.650E
Error (m)	1,894	2,351	1,209
Depth (km)	h = 0.02	h = 0.01	h = 0.01
Origin Time	21:10:04.93	21:10:03.65	21:10:04.11
Error (sec)	+0.13	-1.15	-0.69

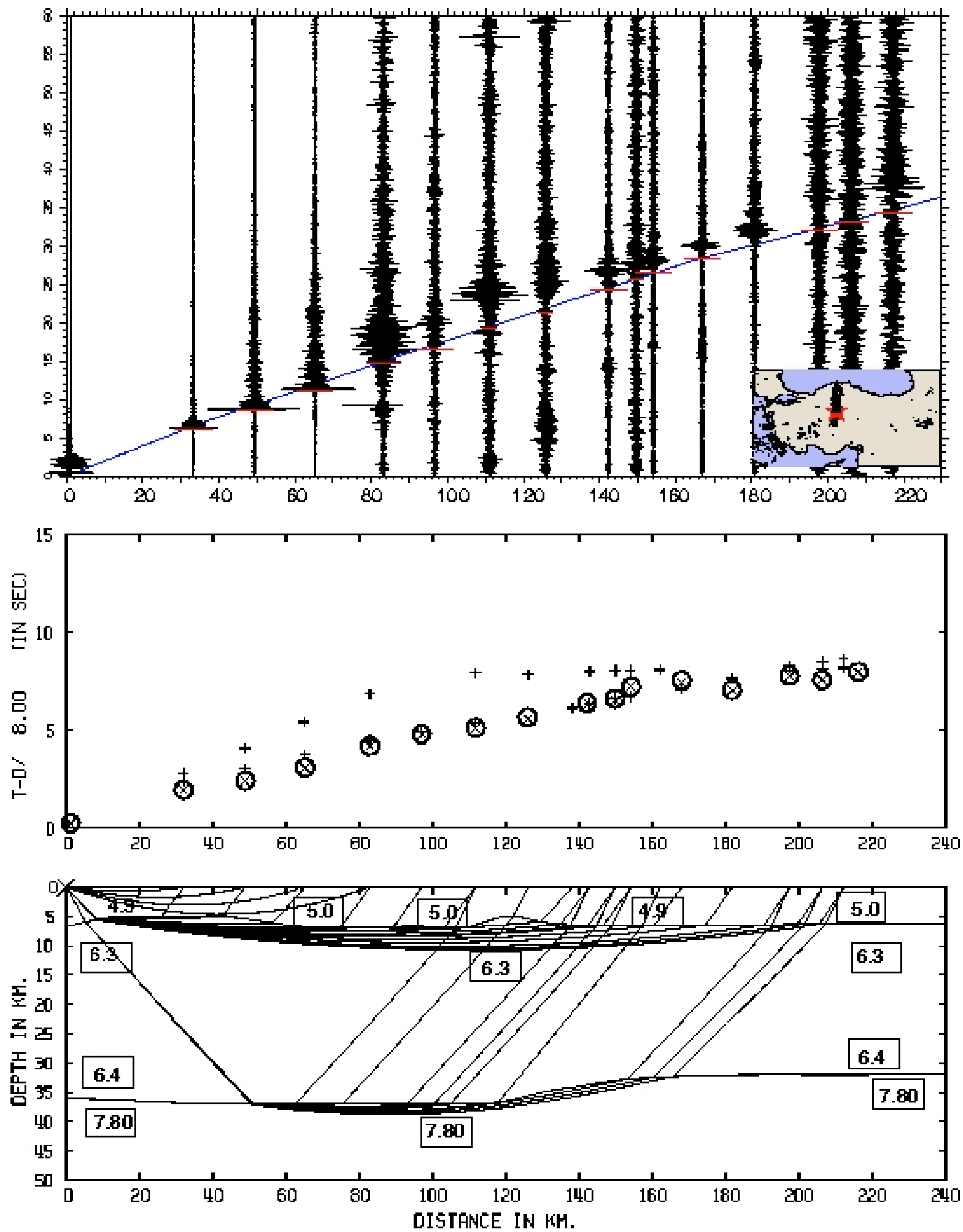

Figure 3: Seismograms and crustal model for the north profile shown in the inset. Top: Record section. Middle: Observed (circles) and calculated (crosses) travel-times. Bottom: Crustal structure and P-wave velocities. Ray paths are also shown. The North Anatolian fault crosses the profile at 170 km distance. Note the crustal thinning across the fault.

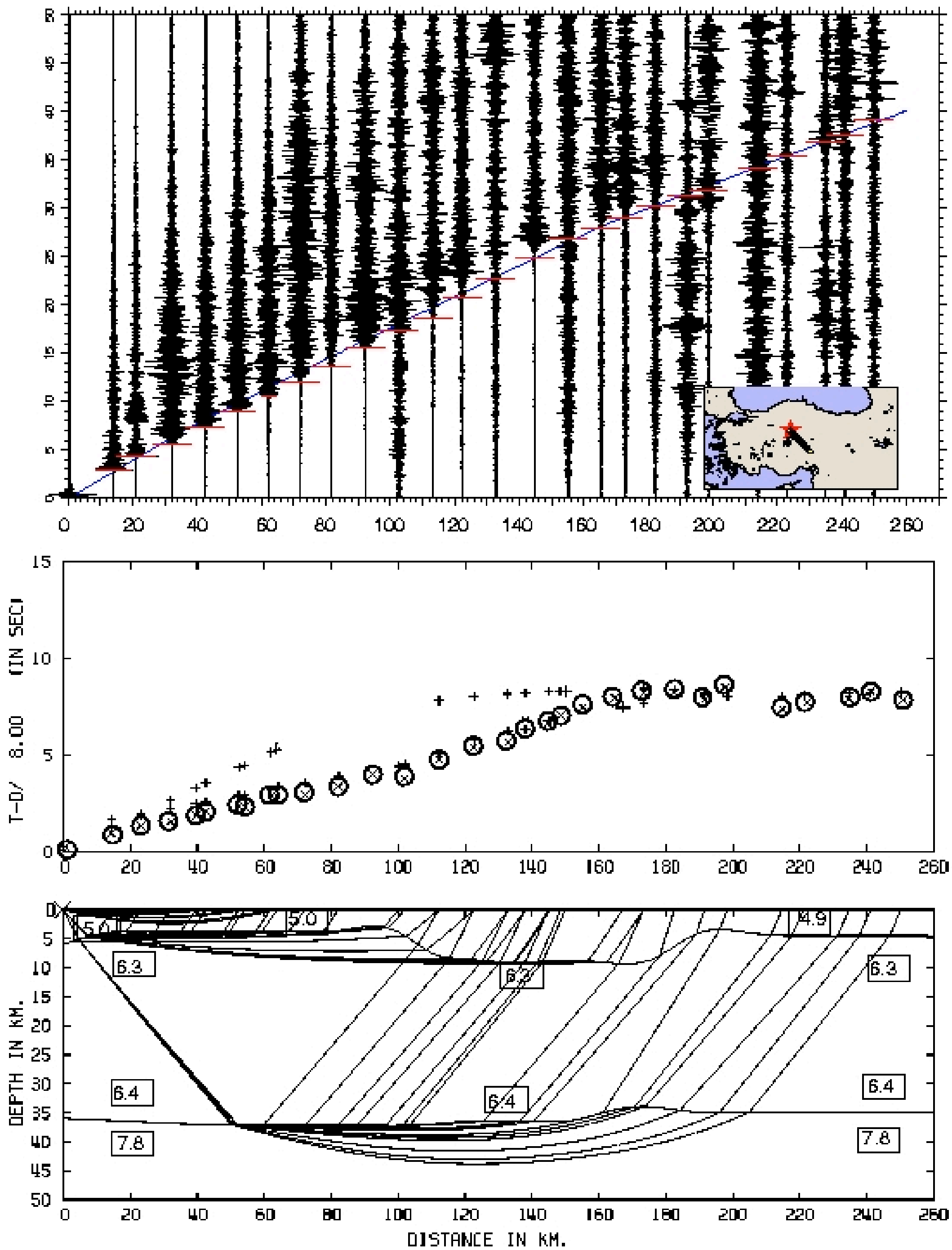

Figure 4: Seismograms and crustal model for the southeast profile shown in the inset. Panels and symbols are the same as in Figure 3. Two fault zones cross this profile at distances of about 100 and 160 km. Note the noisy traces near the fault zones.

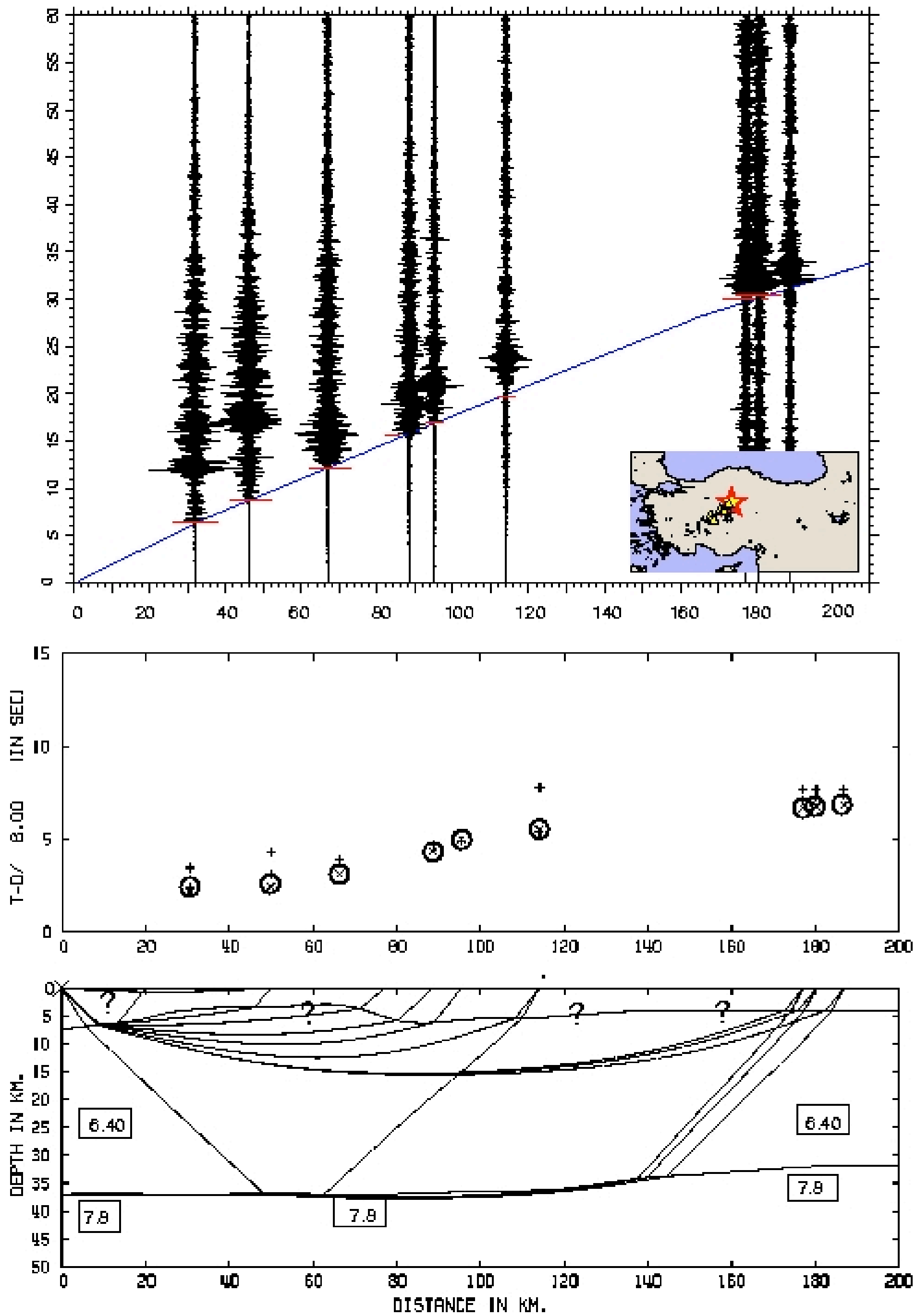

Figure 5: Seismograms and crustal model for the southwest profile shown in the inset. Because of limited data, crustal structure and velocity models are tentative and uncertain.

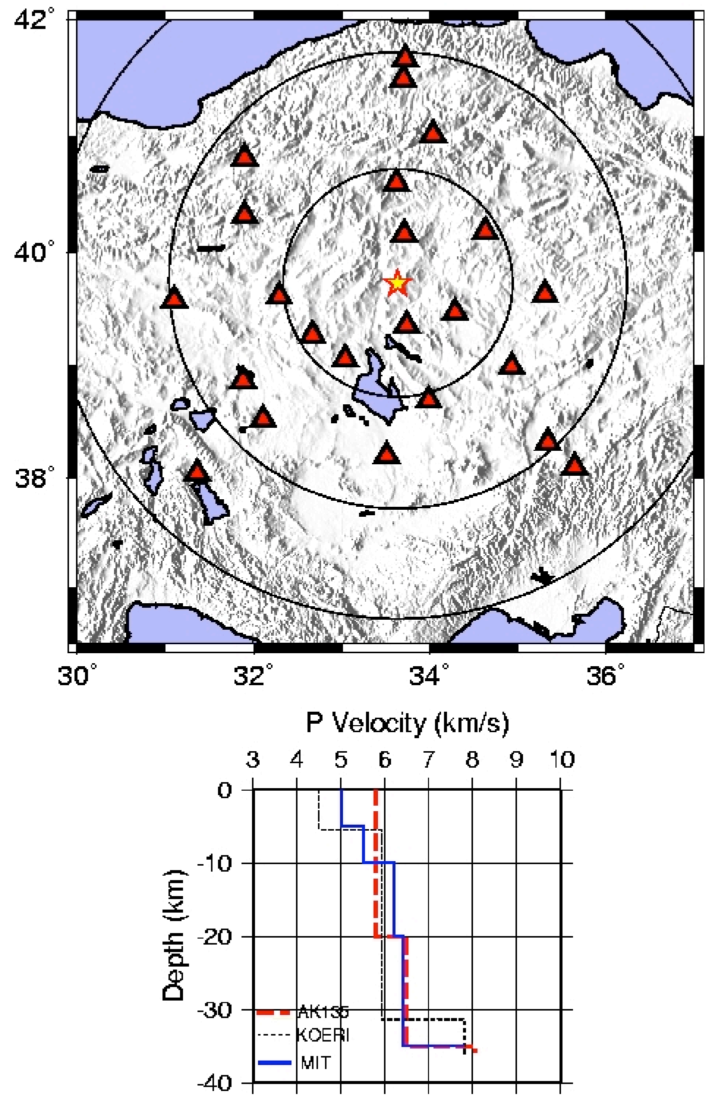

Figure 6: Location of the shot from observed P-wave travel-times. Top: Stations whose arrival times are used. Circles are 1°, 2°, and 3° distances from the shot. Bottom: Three velocity models used for location: AD135; KOERI; and MIT, which is the average of velocities shown in Figures 3, 4, and 5.

Because of good coverage in both azimuthal and distance, all velocity models give accurate locations. However, the velocity model specific to the site gives the best results.

CONCLUSIONS AND RECOMMENDATIONS

The calibration shot at Keskin produced valuable data for obtaining crustal structure and velocities for central Anatolia. The models are the first ever derived from an explosion in central Turkey. The models show that the crust is 36-km thick under Keskin. It can be modeled with two layers, each with velocity gradients. The top layer is about 5–10-km thick, an average velocity of 5 km/sec. The thick lower layer has an average velocity of 6.4 km/sec. The average P_n velocity is 7.8 km/sec.

There are lateral variations in crustal structure and velocities. There is a prominent lateral discontinuity at the North Anatolian fault where the crustal thickness decreases by 5 km from south to north across the fault. There are less prominent structural changes across the Erciyas-Ecemis fault zone. At present, the preliminary crustal models are being refined by calculating synthetic seismograms to match the amplitudes of the first and later arrivals that are observed on the data.

The Keskin shot provided much valuable field experience for deploying and maintaining a large number of portable stations in the field. This experience will help with the planning of field operations for the two large shots to be conducted in Phase II of this project.

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